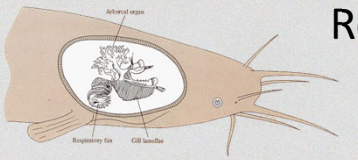
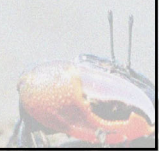


Respiration

Basic problem:

Most gas exchange happens along diffusion gradients. Diffusion is fast on a very local scale, but slow on larger scale (time increases with the square of distance)

Diffusion across the body surface is only enough for (very) animals <1mm along the smallest dimension!



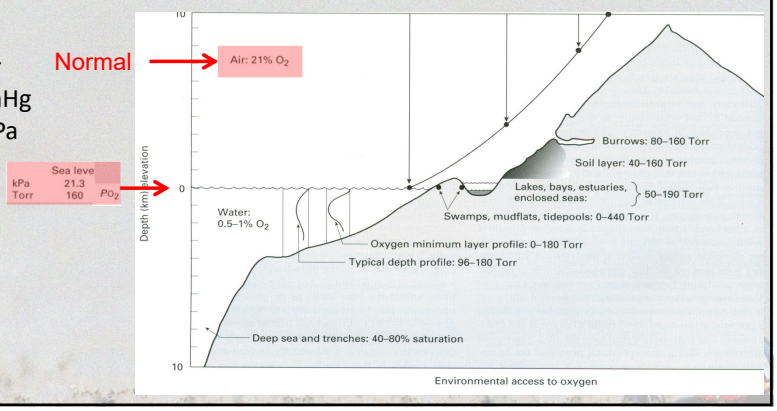
1

Physiological availability of oxygen

Normal air (20.95% O_2)

Partial pressure (pO_2) is the relevant measure of physiological O_2 availability:
$pO_2 = P_b * \% O_2 / 100$ (atm, torr, kPa)

At sea level:
P_b = 1 atm
= 760 torr
= 760 mmHg
= 103.2 kPa



2

Physiological availability of oxygen

Normal air (20.95% O_2)

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$pO_2 = P_b * \% O_2 / 100$ (atm, torr, kPa)

At sea level:
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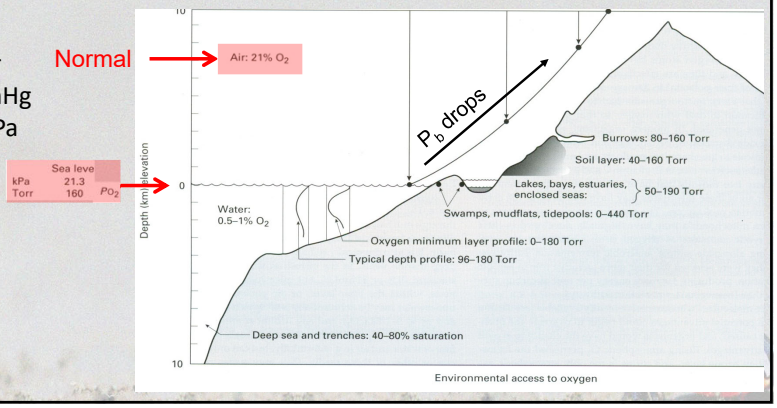


3

Physiological availability of oxygen

At equilibrium, the partial pressure (P) of gas is even across a gas/fluid or across a gas/fluid boundary. But the molecular concentration (Q) in the fluid depends on its solubility:

$Q = \alpha * P$

- Q decreases with water temperature
- Q decreases with salinity

Q_{CO2} is much higher than Q_{O2} and Q_N

4

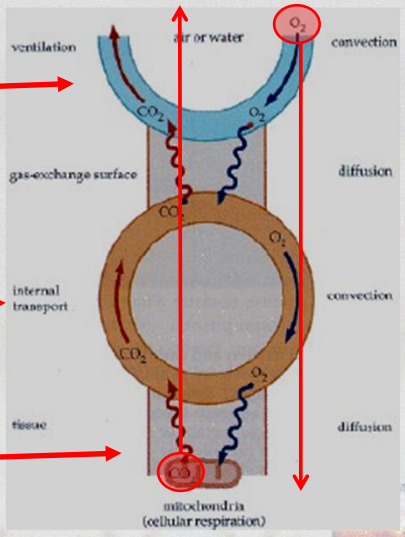
Oxygen cascade

Respiration
(gas exchange) = Ventilation Convection

Pulmonary uptake
Diffusion

Circulation
Convection

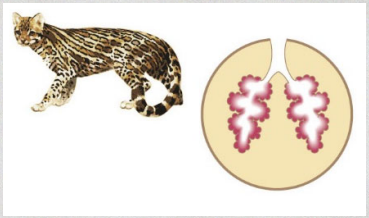
Tissue exchange
Diffusion



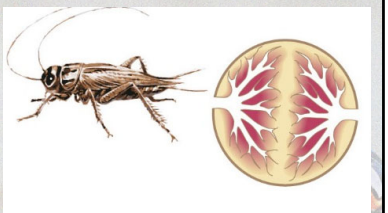
5

Aquatic animals usually have an evaginated GILL (often protected by a rigid covering); water keeps the gill surfaces separated

Air-breathing animals generally have an invaginated LUNG; surface tension of the wet lung surface would stick gill folds together by capillarity (air pressure keeps them apart)



Air-breathing insects (and a few other invertebrates) have a TRACHEA, a system of rigid internal branching tubes, along which O_2 and CO_2 diffuse.



6

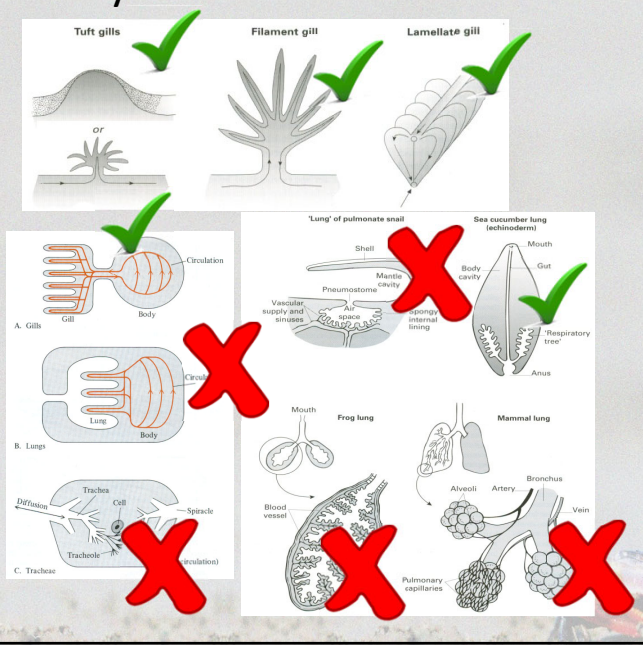
Respiratory Structures in Water

Skin

gills

lungs

trachea



7

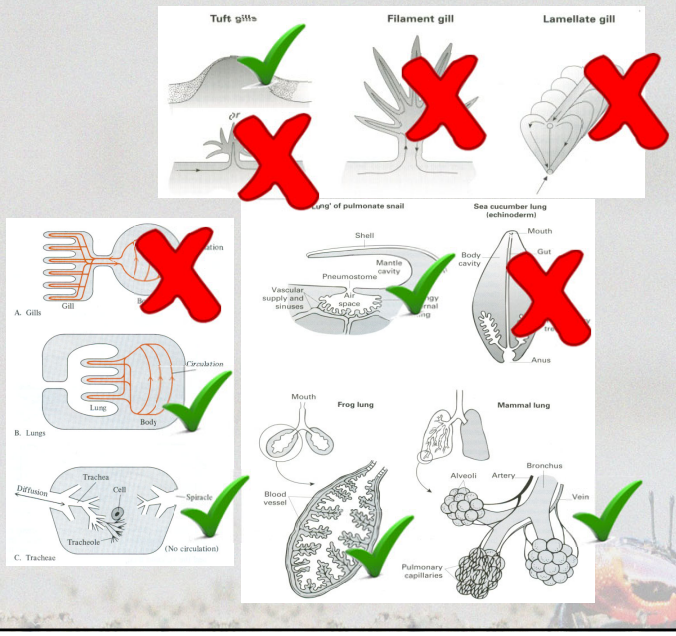
Respiratory Structures in Air

REVIEW
skin

gills

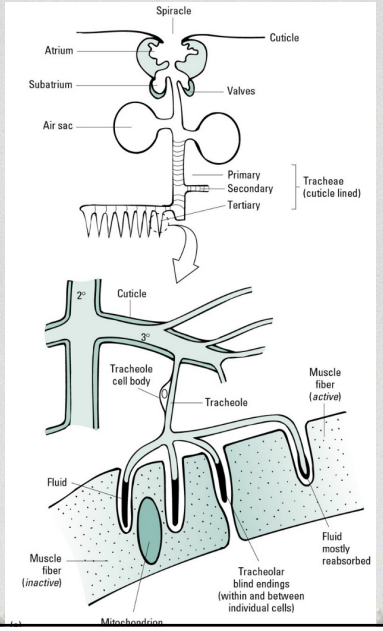
lungs

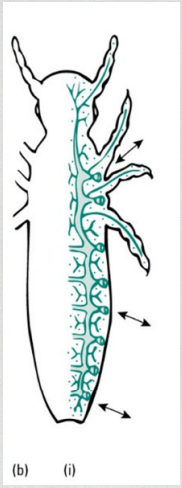
trachea



8

Trachea in insects

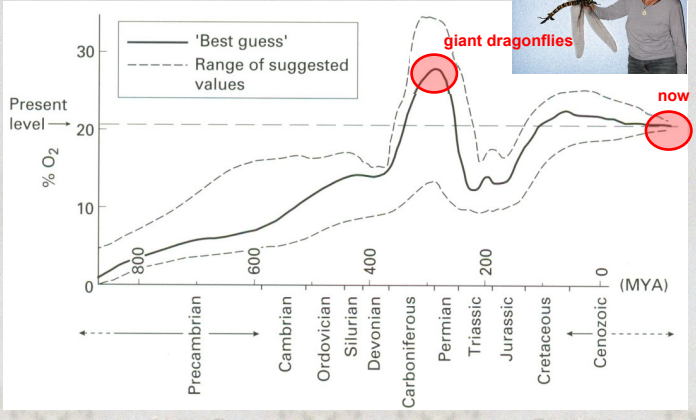




9

Historical availability of oxygen

Historical (geological) variation in atmospheric O_2 levels



20.95%

now

20.95%

10

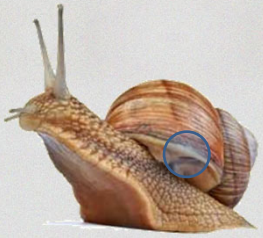
Transitional invertebrates

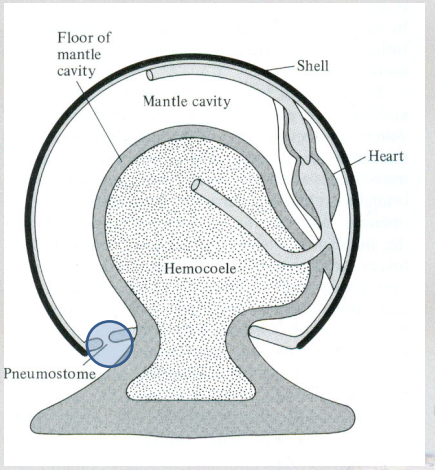
Summary of the invertebrates that have successfully invaded the land.

Class	Description	Gas Exchange Organ
Annelida		
(Oligochetes) Haplotaxidae, Alluroididae, Enchytraeidae	Amphibious and terrestrial worms	Cutaneous surface
Lumbricidae, Megascolecidae, Glossoscolecidae	Terrestrial and burrowing worms	Cutaneous surface
Mollusca		
(Prosobranchiates) Helicinidae, Cyclophoridae, Pomatiasidae	Operculate land snails	Vascularized mantle cavity
Ampullariidae	Amphibious snails	Gills and lung
(Pulmonates) Systellommatophora, Basommatophora	Land snails	Pulmonate lung
Veronicellidae	Tropical slugs	Cutaneous surface
Athoracophoridae	Tropical slugs	Tubular mantle
Onchidiidae	Intertidal slugs	Pulmonary sac
Onycophora	Tropical, temperate, moist habitats	Pseudotracheae
Arthropoda		
Isopoda	Pillbugs, sowbugs	Pleopods, pseudotracheae
Amphipods	Beach/leaf hoppers	Pleopods
Decapoda:		
Macrura	Crayfish	Gills, branchial surface
Anomura	Hermit and coconut crabs	Gills, branchial surface
Brachyura	Fresh water, land, ghost, fiddler, sand-bubbler, soldier crabs	Gills, branchial surface, gas windows
Merostomata	Horseshoe crabs, extinct eurypterids	Book gills and pseudo-tracheae
Arachnida	Scorpions, spiders, ticks	Book lungs and trachea
Chilopoda	Centipedes	Trachea
Diplopoda	Millipedes	Trachea
Insecta	Insects	Book lungs, sieve trachea, trachea

11

Pulmonate snails and slugs



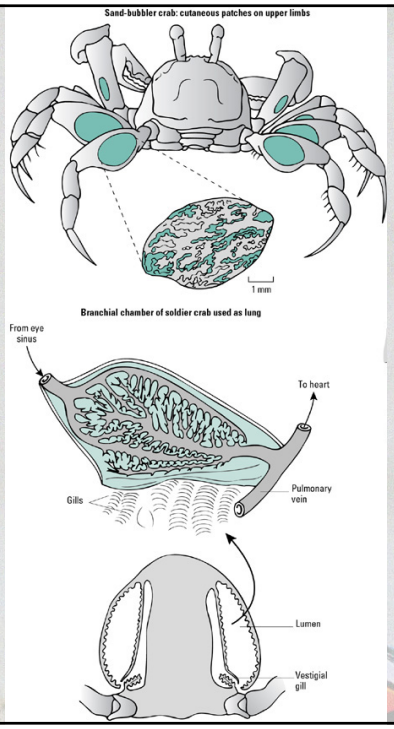


12

Air-breathing crustaceans

Sand bubbler – leg gas “window”

Soldier crab – “lung”



13

Transitional vertebrates (fish)

Taxonomic status, habitat, and the nature of the respiratory surface/organ for a variety of air-breathing fish. The order is in boldface. *(Adapted in part from Dehadrai and Tripathi 1976; Munshi 1976; taxonomic classification after Nelson 1984.)*

	Habitat	Respiratory Surface/Organ
Gymnotiformes		
Electrophorus	SAm rivers, swamps	Buccopharyngeal chamber
Hypoporus	SAm swamps	Vascular opercular chamber
Polypteriformes		
Polypterus	Afr. fresh water	Air sacs
Calamoichthys	Afr. fresh water	Air sacs
Synbranchiformes		
Synbranchus	SAm. swamps	Suprabranchial air sacs
Amphipnous	Asia. ponds. swamps	Suprabranchial air sacs
Siluriformes		
Saccobranchus	Asia, ponds. swamps	Suprabranchial air sacs
Clarias	Afr., Asia, ponds, swamps	Arborescent gill organ
Plecostomus	SAm. swamps	Stomach
Ancistrus	SAm. swamps	Stomach
Doras	SAm. rivers. swamps	Intestine
Erythrinus	SAm. swamps	Swim-bladder
Hoplerythrinus	SAm. swamps	Swim-bladder
Piabucina	SAm. swamps	Swim-bladder
Pangasius	Asia. fresh water	Swim-bladder
Cyrpiniformes		
Misgurnus	Eur. Asia. rivers. pools	Intestine
Lepidocephalichthys	Asia. fresh water	Intestine
Hoplosternum	SAm. rivers. pools	Intestine
Brochis	SAm. benthic still water	Intestine

14

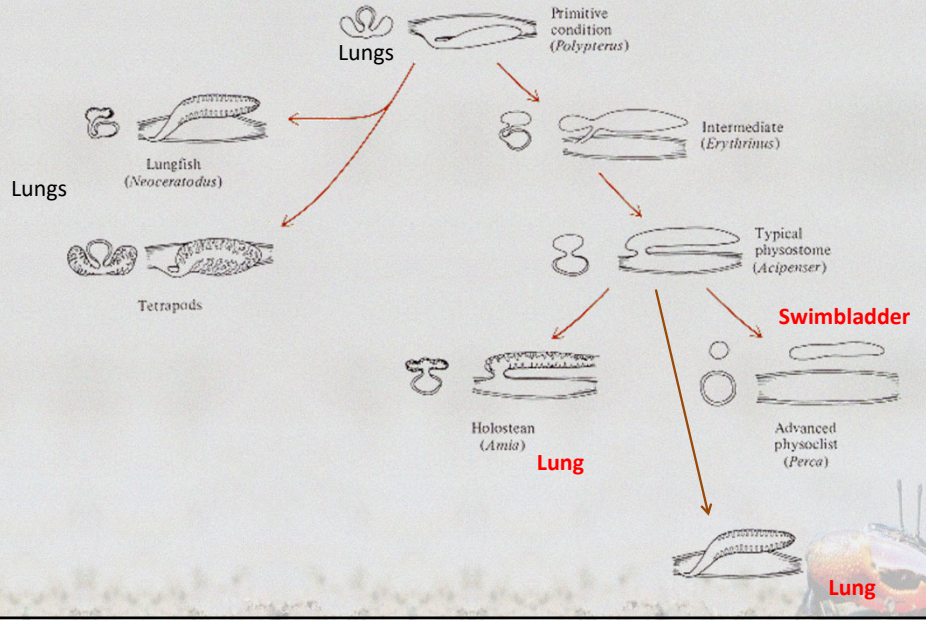
Transitional vertebrates (fish)

Perciformes		
Ophicephalus	Afr, Asia, tropical ponds	Suprabranchial air sac
Pseudapocryptes	Asia, estuaries	Vascularized opercular chamber
Periophthalmus	Asia, estuaries	Skin, opercular chamber
Gillichthys	NAm, estuaries	Bucco-opercular chamber
Macropodus	Asia, tropical ponds	Suprabranchial labyrinth
Colisa	Asia, fresh water	Suprabranchial labyrinth
Betta	Asia, fresh water	Suprabranchial labyrinth
Trichogaster	Asia, fresh water	Suprabranchial labyrinth
Osphronemus	Asia, fresh water	Suprabranchial labyrinth
Anabas	Asia, Afr, swamps	Suprabranchial labyrinth
Mnierpes	SAm, rocky shores	Skin
Anguilliformes		
Anguilla	Eur, Afr, Asia, NAm, rivers	Skin
Amiiformes		
Amia	NAm, fresh water	Swim-bladder
Lepisosteiformes		
Lepisosteus	NAm, fresh water	Swim-bladder
Salmoniiformes		
Umbra	Eur, NAm, stagnant water	Swim-bladder
Osteoglossiformes		
Arapaima	NAm, fresh water	Swim-bladder
Heterotis	Afr, swamps	Swim-bladder
Pantodon	West Afr, fresh water	Swim-bladder
Notopterus	Asia, fresh water	Swim-bladder
Gymnarcus	Afr, swamps, rivers	Swim-bladder
Gonorynchiformes		
Neoceratodus	Aust, rivers	Lung
Lepidosireniformes		
Lepidosiren	SAm, rivers	Lung
Protopterus	Afr, rivers	Lung

[1] SAm = South America, NAm = North America, Eur = Europe, Aust = Australia, and Afr = Africa.

15

Lungs

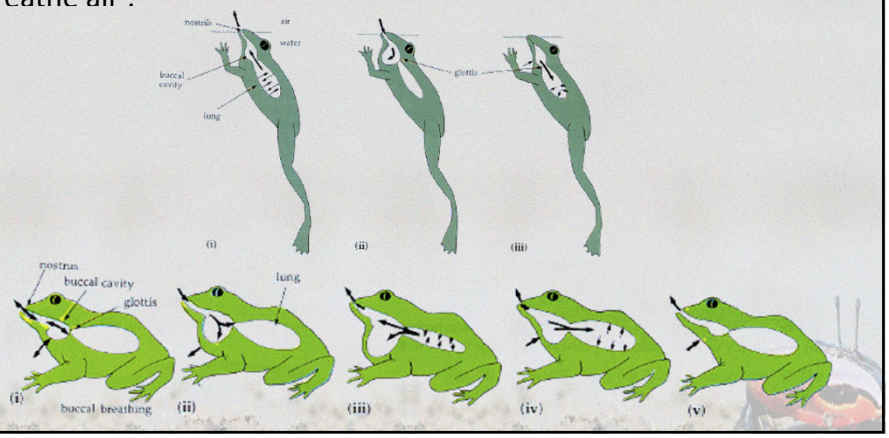


16

Air breathing amphibians

AQUATIC AMPHIBIANS

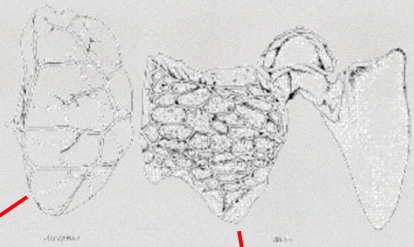
Remember that many air-breathing fishes used a buccal pump to breathe air :

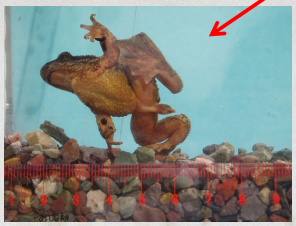


17

Lungs of most amphibians are simple sacs

But there is often some compartmentalisation of the surface to increase its surface area





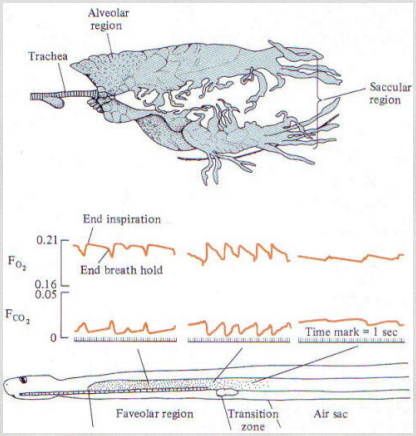
18

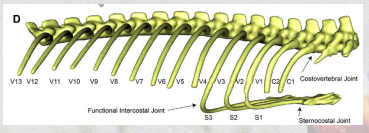
Reptiles - diverse

Lizards and snakes have more complex lungs,

- anterior 'alveolar' section with lots of surface area for gas exchange
- posterior saccular regions that are air 'bellows'.

They also have a rib-cage pump.

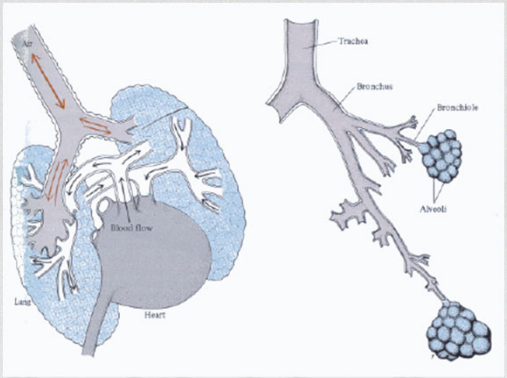


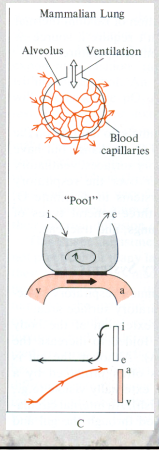

D
V13 V12 V11 V10 V9 V8 V7 V6 V5 V4 V3 V2 V1 C2 C1
Costovertebral Joint
Functional Intercostal Joint
S3 S2 S1
Sternocostal Joint

19

Mammals

Mammals have more complex tidal lungs, with millions of small 'sacs' called alveoli, for gas exchange





20

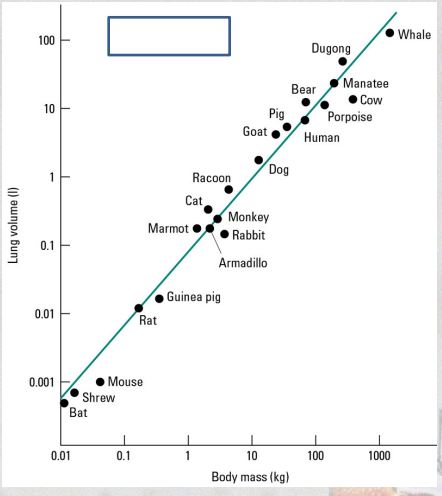
How does long volume scale with body mass in mammals?

Prediction: scales with an exponent of 1 to BMR? i.e. 0.75 to mass?

Result: scales with an exponent of 1 to mass!

This has been explained by a model by West et al 1997, which is based on energy minimisation in the distribution of materials across the body.

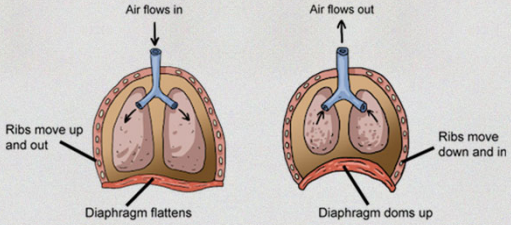
HSM&542556:3wgmirgi26;:2974=2566



21

Breathing in mammals

Inspiration and expiration are due to contraction of intercostal (rib) muscles, and the diaphragm muscle

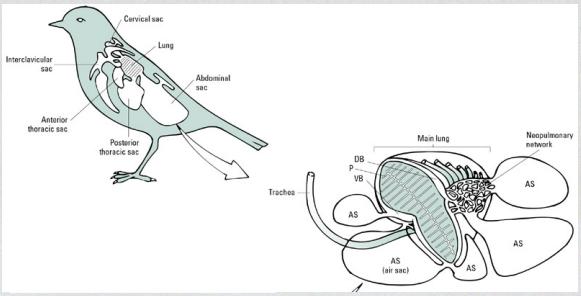


A piston action of the viscera in hopping animals, like kangaroos, aids inspiration and expiration (which are synchronised with hops). So do birds, with wing beats.

22

Birds

Birds have the most unusual and complex respiratory system of vertebrates

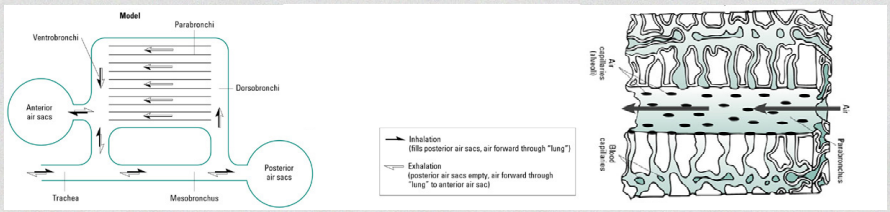


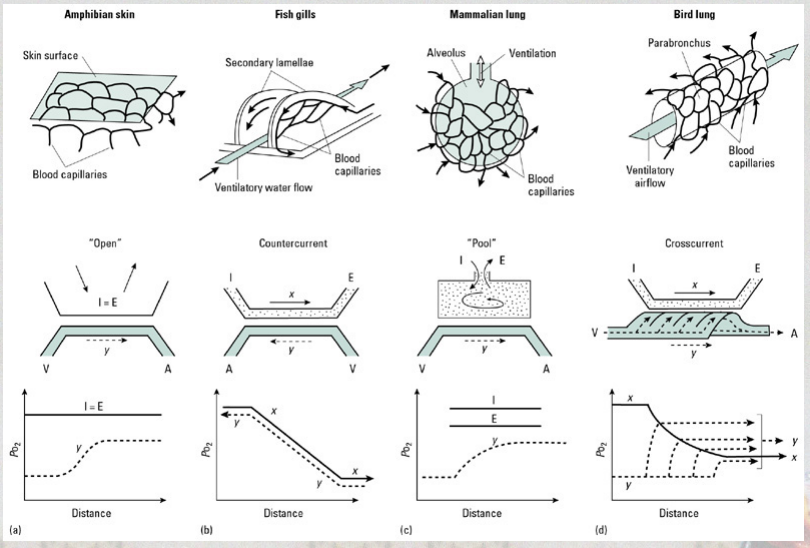
The lungs are fairly rigid air tubes (for gas exchange), and anterior and posterior air sacs act as bellows for air movement

23

One way air flow in bird lungs

The pattern of air flow is complex, to posterior air sacs, to lung, to anterior air sacs, and out



24

Blood flow over respiratory tissue